



Activity Report

December 4th, 2017





Naveen Jindal School of
Management
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Lars Magnus Ericsson Chair
Professor
Director

**THE UNIVERSITY OF TEXAS AT DALLAS
INTERNATIONAL CENTER FOR DECISION AND RISK
ANALYSIS**

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ICDRiA Activity Report 2017

1. INTRODUCTION

The International Center for Decision and Risk Analysis was created in September of 2004 as a Research Center of the School of Management. The objective of the center is to develop education and research programs in the field of Risk Analysis and Decision Making. We report in this document the accomplishments during the period 2017. The cooperation with the Johnson School of Engineering and Computer Science, on the domains of cyber security, systems engineering and energy management is expanding. There is an active cooperation with the mathematics department. The cooperation with City University Hong Kong is developing with visits of PhD students and active collaboration with faculty.

2. FUNDING

2.1 “EREN Development”

Optimization of Wind Farms and Solar Plants Facilities: Competitive Markets

Alain Bensoussan (PI)

150,000€ (\$190K)

October 20, 2014 – October 19, 2017

This activity is performed with Professor Alexandre Brouste, University du Maine, as co PI. Professor Brouste is associated with the center. As indicated below, a cooperative agreement has been signed with the Université du Maine and the Institut du risque et de l’assurance, of this university.

2.2 Mean Field Games, Mean Field Type Control and Extensions

National Science Foundation
Alain Bensoussan (PI)
\$ 339,572, October 1, 2013- September 30, 2017

2.3 New Problems in Mean Field Control Theory

National Science Foundation
Alain Bensoussan (PI), Jameson Graber (co-PI)
\$ 208,559. October 1, 2016 – September 30, 2019

2.4 RGC, General Research Fund, Hong Kong

Mean Field Control with Partial Information
Alain Bensoussan (PI)
HK\$ 727,647. January 1, 2017 – December 31, 2019

We recall the objective of the contract with EREN Development. We are dealing with new markets, for which there is no precedent. So far, the power providers, relying on wind and solar energy, can benefit from a privileged status, which is the consequence of the general political will to reduce environmental risks, occurring from classical power plants. Their profitability is protected by a system of subsidies or guaranteed markets. This is changing rapidly. The providers, exploiting a park of turbines or solar plants, will compete on markets which will be open and without backing from public sources. In this context, the profitability will highly depend on the way risks are managed. In view of the fact that things can change fast, and that many players will enter these new markets, the best preparation will be an essential asset for success.

The type of problem to be faced by the provider is to guarantee a given amount of energy, for a given duration, at a given price. The contract commitment is for some future date, which can be short term or longer. The major difficulty is that the capacity of production comes from wind turbines and solar plants. Therefore, this capacity is highly dependent on the wind speed and direction, or sun availability. Consequently the capacity is highly random. The problem is to assess the risk of bidding for a contract.

Last year we developed short term forecasting models for wind speed. This year, we go further in defining the level of storage needed to achieve an optimized profitability. The storage reduces the risk of not producing an amount compatible with commitments in which case a penalty occurs. On the other hand this storage capacity, obtained with batteries is a costly investment. The problem is to find the right capacity of the battery.

Concerning NSF, we proceed with the grant on mean field control theory. This is done jointly with Dr. Jameson Graber as a co PI. Dr. Graber has now a position at Baylor University.

3. AGREEMENT WITH UNIVERSITE DU MAINE.

International Collaborative Research Agreement This

International Collaborative Research Agreement (the "Agreement") is made BETWEEN:

The University of Texas at Dallas ("UT Dallas"), a component institution of The University of Texas System ("System"), located at 800 W. Campbell Road, Richardson, Texas 75080, on behalf of The International Center for Decision and Risk Analysis (ICDRiA) at UT Dallas

shall be referred to herein as a

"Party" AND

The Universite du Maine, Le Mans (UM), SIRET 197 209 166 000 10, a higher education and research institution located at Avenue Olivier Messiaen 72085 LE MANS cedex 9, France, and her Institut du Risque et de l' Assurance du Mans (IRA),

Shall be referred to herein as a "Collaborator"

The University of Texas at Dallas and the Universite du Maine, hereinafter, jointly or individually, also referred to as "Party" and "Collaborator"

RECITAL

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Collaborator desires to work with UT Dallas in performing certain research

hereinafter described;

and

The Parties desire to protect rights to intellectual property developed during the course of such research; and

-.....

The Parties are willing to collaborate to perform research and to negotiate rights to intellectual property, if any.

1. EFFECTIVE DATE

This Agreement shall be effective as of May 1, 2017 (the "Effective Date").

2. RESEARCH PROGRAM

2.1 UT Dallas and Collaborator will use reasonable efforts to conduct the research program described in Attachment A ("Research Program"), and will furnish the facilities necessary to carry out the Research Program. The Research Program will be under the direction of Alain Bensoussan, Ph.D. for UT Dallas or his/her successor (the "UT Dallas Investigator") and Alexandre Brouste, Ph.D. for Collaborator or his/her successor (the "Collaborator Investigator"), as may be mutually agreed to by the Parties by written amendment to this Agreement.

2.2 The Research Program shall be performed during the period from the Effective Date through and including May 31, 2022 ("Term"). The Parties may extend the Research Program under

mutually agreeable terms by written amendment to this Agreement.

2.3 Both Parties' mission is advancement of knowledge and education and, consequently, the Research Program will be designed to carry out that mission. Neither Party guarantees specific results.

2.4 Both Parties understand that the other Party may be involved in similar research through other researchers on behalf of itself and others. The Parties shall be free to continue such research provided that it is conducted separately and by different investigators from the Research Program, and a Party shall not gain any rights via this Agreement to such other research.

2.5 The Parties do not guarantee that any intellectual property rights will result from the Research Program, that the scope of any intellectual property rights obtained will cover a Party's commercial interest, or that any such intellectual property rights will be free of dominance by other rights independent of the Research Program.

3. CONSULTATION AND REPORTS

3.1 During the Term of the Agreement, UT Dallas Investigator and Collaborator Investigator may consult informally with each other regarding the Research Program, both personally and by telephone. Access to work carried on in UT Dallas laboratories in the course of these investigations shall be entirely under the control of UT Dallas personnel but shall be made available on a reasonable basis.

3.2 At the conclusion of each year of the Research Program, each Party's respective Investigator shall submit to the other Party a written report summarizing the work. The Parties shall also submit a comprehensive final report within one hundred twenty (120) days of termination of the Agreement which shall contain, but which need not be limited to, a report of the activities undertaken and accomplishments achieved by UT Dallas and/or Collaborator under the Research Program.

3.3 Except as otherwise agreed to by the Parties in writing, each Party agrees to be responsible for its own expenses associated with participating in the Research Program. Either Party may dispatch its research personnel, including students, to the other Party's location to work on the Research Program. Except as otherwise agreed to by the Parties in writing, the dispatched research personnel shall be fully supported by the dispatching Party for his/her/their visa, salary, living expenses, health care benefits and personal insurances during term of the dispatched research personnel's visit to the other Party's location. The Party dispatching the research personnel agrees, to

the extent authorized by the Constitution and laws of the State of Texas, to indemnify and hold harmless the other Party for any damages incurred by the dispatched research personnel while on the other Party's premises, unless such damages are caused by the other Party's negligence or wrongful misconduct. Each Party is responsible to ensure that its dispatched research personnel becomes aware of, fully informed about and in full compliance with the other Party's applicable rules, including those related to personal health, security, environmental quality, safety, fire prevention, noise, smoking and access restrictions.

5. PUBLICITY

Neither Party shall make reference to the other in a press release or any other written statement in connection with the Research Program, if it is intended for use in the public media, except as required by The Texas Public Information Act or other law or regulation. Each Party, however, shall have the right to

acknowledge the other Party's involvement in the investigations under this Agreement in scientific or academic publications and other scientific or academic communications, without the other Party's prior approval. In any such statements, the Parties shall describe the scope and nature of their participation accurately and appropriately.

6. PUBLICATION AND ACADEMIC RIGHTS

6.1 Both Parties have the right to publish or otherwise publicly disclose information gained in the course of this Agreement. In order to avoid loss of a Party's patent rights as a result of premature public disclosure of patentable information, the Party seeking to publish will submit any prepublication materials to the Party seeking patent protection for review and comment at least thirty (30) days prior to planned submission for publication. The Party seeking patent protection shall notify the Party seeking to publish within thirty (30) days of receipt of such materials whether it desires to file patent applications on any inventions contained in the materials; and, if UT Dallas agrees to do so, UT Dallas will proceed to file a patent application in due course.

6.2 It is understood that each respective Party's Investigator may discuss the Research Program with other investigators but shall not reveal information which is the other Party's Confidential Information under Article 7. In the event any joint inventions result from such discussions, the relevant Party's Investigator shall disclose such joint invention to the other Party as outlined in Article 8 of this Agreement. To the extent such joint inventions conflict with obligations to another party as a result of the involvement of the other investigator(s), the Parties shall, in good faith, exercise reasonable efforts to enable the other Party to obtain rights to the joint invention(s).

7. CONFIDENTIAL INFORMATION

7.1 The Parties may wish, from time to time, in connection with the Research Program, to disclose confidential information to each other ("Confidential Information"). Each Party will use reasonable efforts to prevent the disclosure of any of the other Party's Confidential Information to third parties for a period of three (3) years from receipt thereof, provided that the obligation of the receiving Party shall not apply to information that:

- (1) is not disclosed in writing or reduced to writing and so marked with an appropriate confidentiality legend within thirty (30) days of disclosure;
- (2) is already in the receiving Party's possession at the time of disclosure thereof;
- (3) is or later becomes part of the public domain through no fault of the receiving Party;
- (4) is received from a third party having no obligations of confidentiality to the disclosing Party;
- (5) is independently developed by the receiving Party; or
- (6) is required by law or regulation to be disclosed.

7.2 In the event that information is required to be disclosed pursuant to Article 7.1, subsection (6), the Party required to make disclosure shall notify the other to allow that Party to assert

whatever exclusions or exemptions may be available to it under such law or regulation.

8. INTELLECTUALPROPERTY

An "Invention" will be any invention or discovery that results from the performance of the Research Program during the term of the Agreement. Inventorship of an Invention will be determined under United States Patent Law. Ownership will follow inventorship. If a Party becomes aware of an Invention, it will be disclosed in confidence to other Party within thirty (30) days of such knowledge. The

Parties agree to enter into a separate agreement governing disposition of any jointly invented Invention and will negotiate in good faith on such agreement.

9. LIABILITY

9.1 To the extent allowed by the laws, regulations and rules governing their institutions, each Party agrees to indemnify and hold harmless the other Party, its System, University, their Regents, officers, agents and employees (the "Indemnitees") from any liability, loss or damage they may suffer as a result of claims, demands, costs or judgments against them arising out of the activities to be carried out pursuant to the obligations of this Agreement, including but not limited to the use of the results obtained from the Research Program performed by the Parties under this Agreement; provided, however, that the following is excluded from a Party's obligation to indemnify and hold harmless:

1. the negligent failure of a Party to substantially comply with any applicable governmental requirements; or
11. the negligence or willful malfeasance of a Party's Regent, officer, agent or employee.

9.2 Both Parties agree that upon receipt of a notice of claim or action arising out of the Research Program, the Party receiving such notice will notify the other Party promptly. Each Party agrees, at its own expense, to provide attorneys to defend against any actions brought or filed against the Indemnitees with respect to the subject of the indemnity contained herein, whether such claims or actions are rightfully brought or filed; and subject to the statutory duty of The Texas Attorney General, each Party agrees to cooperate with the other Party in the defense of such claim or action.

10. INDEPENDENT CONTRACTOR

For the purposes of this Agreement and all work connected to the Research Program, the Parties shall be, and shall be deemed to be, independent contractors and not agents or employees of the other Party. A Party does not have authority to make any statements, representations or commitments of any kind, or to take any action which shall be binding on the other Party, except as may be expressly provided for herein or authorized in writing.

11. TERMANDTERMINATION

11.1 This Agreement shall commence on the Effective Date and extend until the end of the Term as described in Article 2.2, unless sooner terminated in accordance with the provisions of this Article 11.

11.2 This Agreement may be terminated at any time by the written agreement of both Parties.

11.3 In the event that either Party shall be in default of its material obligations under this Agreement and shall fail to remedy such default within thirty (30) days after receipt of written notice thereof, this Agreement shall terminate upon expiration of the thirty (30) day period.

11.4 Termination or cancellation of this Agreement shall not affect the rights and obligations of the Parties accrued prior to termination.

11.5 Any provisions of this Agreement which by their nature extend beyond termination shall survive such termination.

12. AITACHMENTS

Attachment A, Research Program, is incorporated and made a part of this Agreement for all purposes.

13. GENERAL

13.1 This Agreement may not be assigned by either Party without the prior written consent of the other Party; provided, however, that subject to the approval of UT Dallas, which may not be unreasonably withheld, the parties may assign this Agreement to any purchaser or transferee of all or substantially all of the parties' assets or stock upon prior written notice to the other party, and both parties may assign its right to receive payments hereunder.

13.2 This Agreement constitutes the entire and only agreement between the Parties relating to the Research Program, and all prior negotiations, representations, agreements and understandings are superseded hereby. No agreements altering or supplementing the terms hereof may be made except by means of a written document signed by the duly authorized representatives of the Parties.

13.3 Any notice required by this Agreement by Articles 8, 9, or 11 shall be given by prepaid, first class, certified mail, return receipt requested, addressed in the case of UT Dallas to:

The University of Texas at Dallas
Office of Sponsored Projects
800 W. Campbell Rd., AD15
Richardson, TX 75080-3021
ATTN: Research Contracts
Specialist FAX: (972) 883-2310
PHONE: (972) 883-2313

EMAIL:

osp@utdallas.edu or in the case of

Collaborator to:

Universite du Maine at Le Mans
Avenue Olivier Messiaen
72085 LE MANS Cedex 9
Research Services

Mrs Nathalie METAIRIE PHONE:02 43 83 30 09

EMAIL: contrats-recherche@univ-lemans.fr

or at such other addresses as may be given from time to time in accordance with the terms of this notice provision.

[Signature Page to
Follow]

13.4 This Agreement shall be governed by, construed, and enforced in accordance with the internal laws of the State of Texas.

IN WITNESS WHEREOF, the Parties have caused this Agreement to be executed by their duly authorized representatives.

THE UNIVERSITY OF
TEXAS AT DALLAS

UNIVERSITE DU MAINE
LEMANS


Rachid El Guerjouma
Chairman

.Xslo I.Pt
Date

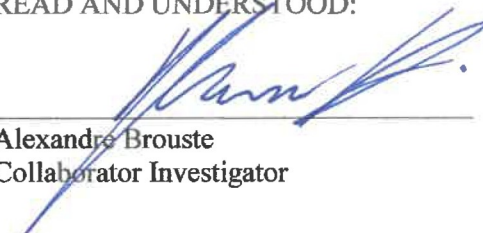
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Interim Vice e
President Office of
Research

READ AND UNDERSTOOD:

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READ AND UNDERSTOOD:


Alexandre Brouste
Collaborator Investigator

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Attachment A RESEARCH

PROGRAM

Future Activities

The International Center for Risk and Decision Analysis (ICDRiA) created at UTD in 2004 and the Institute of Risk and Insurance created at UM in 2012 will build on their respective knowledge and develop a common expertise.

Joint research in the domains of Insurance, Risk and Decision Analysis and Risk in Alternative Energies will be performed by scholars of the two Universities under the auspices of ICDRiA and IRA. Professor Alain Bensoussan and Alexandre Brouste will be responsible for coordinating the joint research strategy and the cooperative programs.

ICDRiA at UTD and IRA at UM will facilitate the participation of additional centers from both universities.

There will be a single web site, with appropriate links and references to the web sites of the two partners. The funding will be separate in view of the specific aspects and the geographic conditions of the two institutions.

Extensions

The primary purpose of the partnership relates to research. Nevertheless, contacts with industries on both sites will be strongly considered. The possibility of funding from international cooperation will be explored.

Organizing conferences and training programs are certainly a good way to enhance visibility. We will sponsor workshops and seminars including additional partners worldwide.

4. EDUCATION PROGRAM

Risk and Decision Analysis is included in the education programs of the Jindal School of Management. The course is taught in the fall every other year and is also part of the program "Systems Engineering and Management" which is a joint venture between the School of Engineering and the School of Management. The course is now well established, although not taught anymore by Alain Bensoussan.

The course “Introductory Mathematical Finance” has been offered as a part of the Master in Finance in fall since 2008. After initial ICDRiA involvement, the course has been directly taught within the finance area.

The major effort is now devoted to the new class “Stochastic Dynamic Programming and applications to Operations Management and Finance” which started in fall 2015. Starting fall 2018, the class will be cross listed by the Mathematics department and the Jindal School of Management.

Stochastic Dynamic Programming is a general methodology which plays an essential role in many areas of economics and management science. It deals with decision making under uncertainty for dynamic systems, which is the situation appearing commonly in a lot of applications. Although this fact has been known for long time, it has become even more evident in view of the new problems which are presently at the forefront of research.

This is particularly true for mathematical finance, whose developments have motivated many innovative techniques related to SDP (Stochastic Dynamic Programming). The consumer-investor problem of Merton is the most famous one, but option pricing, credit risk, corporate finance, optimal compensation and many others have originated substantial new effort and interest in SDP related techniques.

In Operations Management, the application of SDP goes back to inventory theory, with the well-known base stock and s, S policies. However, the structure of the supply chain has become very complex, and has justified new approaches, in particular the use of principal-agent methodology. For realistic situations, one has to consider dynamic systems, with moral hazard problems, asymmetric information, risk-sharing issues and incentive considerations. A lot of interest is related to linking Operations Management with other management domains, like Marketing and Finance. The issue of pricing, traditionally a marketing question, is now considered together with capacity planning and inventory control. This new and very important topic is called revenue management. Dynamic models are essential, and lead to substantial extension of SDP.

Investment theory, growth of firms and real options are now connected and elicit new questions related to SDP methodology. As soon as there are several decision makers, in competition, or contracting with each other, the issue of information comes naturally, with very delicate questions, for which intuition is of little help. A solid theory requiring sophisticated mathematical techniques is imperative. Even if mathematics is not the objective, it is indispensable to be comfortable with some of these techniques and concepts.

The case of a very large number of decision makers leads to the question of dynamic equilibrium, topics of strong interest in economics, but also for financial markets, and social networks. “Big data” has become the new framework, and involves new statistical problems, advanced simulation techniques and stochastic optimization with dynamic structure. All these considerations have amply modified the type of background which is indispensable to perform relevant research in the current circumstances. They all have to do with stochastic dynamic programming and its evolution.

5. RESEARCH PROGRAM

The activities of the center are presented in 5 domains:

- Risks and Uncertainties in Information Systems;
- Risks in Supply Chain Management;
- Risks in Financial and Economic Systems;
- Risks and Uncertainties in alternative energies;
- Risks in Technical Systems.

5.1. RISKS AND UNCERTAINTIES IN INFORMATION SYSTEMS

The center benefits from the activity of a group of faculty focused on security issues in information systems, a major strength of the School of Management. The center cooperates also with the Cyber-security Center of the School of

Engineering, headed by Professor Bhavani Thuraisingham. Currently, Alain Bensoussan is Co-PI of one NSF grant, with Murat Kantarcioglu as P.I.: TWC *Medium: Collaborative Incentive Compatible Privacy Preserving Data Analytics, which runs till 2018.*

We have now obtained a set of interesting models, dealing with IDS (Intrusion Detection Systems), Hackers and Botnets. We use control theory as well as differential games. We look at defense in cybersecurity as an investment, to be dealt with the framework of cost-benefit analysis. In the botnet project, the interesting aspect is that there is a market of malignant actions. An entity interested in being harmful to another entity buys the services of a botnet herder. A botnet herder has contaminated a network of computer systems without the owner's knowledge. He can drive these systems to perform damages on targeted systems. The problem that we have treated is the calibration of the defense effort.

One can define a criterion for the botnet herder. This criterion is itself the result of equilibrium on the market. There is a price for the malignant actions and the herder optimizes an objective based on his profit and costs (including risks). The defense can then formulate a game based on its' own criterion and that of the botnet herder. We have considered and solved completely a dynamic game based on these considerations.

In a recent extension, we consider the possibility of random attacks, modelled as a compound Poisson process. We show the existence of a random steady state.

A new recent finding concerns connections between Mean Field Games and Cybersecurity. Indeed, let us take the situation of botnets. We have a large network of computers. Each of them is an individual agent, which has a defense strategy and a level of infection. But the more the network is infected, the more each computer will face a risk of infection, because of contamination, as in the spreading of epidemics. With a colleague from Warwick University, we have found that this aspect is amenable to Mean Field Games theory, so that we can consider the network as an entity, characterized by a state of infection. In this way, the averaging effect leads to a substantial simplification in defining the defense strategy.

The model developed so far is binary. The system is infected or not, there is defense or not. We want now to consider a level of infection which is continuous, as well as a continuous level of defense.

Unfortunately, our MURI proposal for the ONR Program "Cyber Deception through Active Leverage of Adversaries Cognition Process" failed, in spite of the fact that a white paper had been accepted by ONR. We are now involved in a new MURI competition, regarding an AFOSR program: Advanced Mean-Field Game Theory for Complex Physical & Socio-Economical Systems. The P.I. is with the University of Maryland.

5.2. RISKS IN SUPPLY CHAIN MANAGEMENT

In the "supply chain" area, the center relies mainly on the expertise of the Operations Management department. Risk arises from uncertainties at all stages of the supply chain. In particular, there are uncertainties on key variables needed to make decisions. For instance, one does not know the inventory and one must decide on the level of replenishment. Uncertainties on inventories have been at the core of our research since many years.

We have developed a general methodology which provides the optimal policy for managing inventories in the context of uncertainties. Our approach is now commonly referred in the field. We have provided a comparative analysis of approximations in order to define relatively simple solutions, still sufficiently accurate. The mean variance approximation is an innovative one, representing a meaningful example.

Our approach follows the idea of fault tolerant systems. We do not correct the pathology, which is the uncertainty, but we incorporate it in the decision making. In practice we may combine both.

A general situation in which the methodology works well is *learning*. This is a common situation in which one tries to learn about the demand. Demand is of course an essential source of risk for companies and also provides a wide diversity of modeling possibilities. This domain leads to very interesting developments, in connection with

inventory theory. If we can observe the past demands, basic results of inventory control can be extended. The problem is rather complex if we observe the sales instead of the demand.

Inventory Management in the context of global supply chain is the source of numerous research problems. In fact, it is more and more connected to the definition of contracts with suppliers. Big issues concern the setting of incentives, the issue of moral hazard, the sharing of risks and the lack of information.

In these new directions, we have initiated two actions, involving new participants at UTD as well as in Hong Kong. One concerns a “Principal-Agent approach to inventory control” We propose a contractual approach between a supplier and a retailer. The inventory manager, the supplier or principal, proposes a contract to the retailer, based on a replenishment policy of base stock type. This guarantees the availability of the product to the retailer, against the payment of a premium. There is an asymmetry of information. The retailer (Agent) knows the demand better than the supplier (Principal). He provides some information to the principal. The issue for the principal is to design the contract so that it has the revealing property; the agent has no interest in distorting the information. Besides the design of the contract, the problem of the principal is to choose the time when he proposes the contract. This leads to problems of optimal stopping in inventory control with partial information, which is new and challenging. We have enhanced our previous results, by incorporating the possibility that the agent rejects the offer of the principal in which case the current arrangement is continued. So the principal should propose a contract at least as favorable as the current one.

The second direction initiated in Hong Kong concerns simultaneous inventory and pricing optimization. This is a very natural problem, considered in the literature with primitive techniques. More advanced mathematical techniques should be used to handle it. The version in continuous time has never been considered in the literature. We have solved the case called “base stock, list price” in the literature, studied in discrete time. It is the topic of the dissertation of a PhD candidate in the mathematics department. We have also worked on the case of set up cost. Moreover, when prices are decision variables, we have a natural extension to games, when firms compete in pricing. This is an extremely challenging problem, offering a lot of possibilities.

Finally, we try to extend the Base stock and s,S policy to intermediary situations, in which the ordering cost is concave bilinear. We also try to introduce machine learning methods. This is quite preliminary.

5.3. RISKS IN FINANCIAL AND ECONOMIC SYSTEMS

In the third direction, we are considering several questions. Financial Engineering is a particularly challenging domain, and the 2008 crisis has introduced new research aspects. In particular, there should be stronger connections between financial decisions and risk management and between the financial world and the ‘real world’.

In the context of coupling the financial world to the real world, we are particularly active in the area of “Real options,” which aims at adapting techniques from financial engineering in project risk management.

On the more theoretical side, we have been working on problems of real options when there is competition. This is an extremely interesting but challenging problem. In real options, the number of competitors is generally limited whereas for financial options the multiplicity of players allows to assume that a single player cannot alone modify significantly the market (this is of course not always true). Therefore, integrating competition in the model is important.

We have obtained significant results, with Celine Hoe, who now holds a position at Texas A&M. With another former post-doc, Benoit Chevalier-Roignant, who holds a position at King’s College, we have connected the methodology of real options to that of building capital in firms. This is a very well-known problem in economics, under the name of growth of firms. On the contrary, real options are linked with management science and finance.

These questions have been considered separately in the literature. They are obviously linked; a firm builds its capital through projects. We can formulate the general problem as an impulse control problem. We have obtained new results, to characterize the optimal policy. It must be emphasized that, in spite of a huge literature, only partial

results existed so far. Several publications are under way. The impulse control problems which arise in this context are quite new and challenging. We have delicate free boundary problems to solve.

A major effort of research is devoted to *Mean Field Theory*. This is a direction of research initiated a few years ago, which has become extremely popular in many countries. The general idea is to apply concepts well known in Physics, and deemed very useful, to social and economic sciences. The objective is to study the systemic risk, and more generally the influence on decisions of a large community of agents, with characteristics similar to the decision-maker. This impact is in general discarded, because of its complexity. Note that this is different from equilibrium theory in economics.

In equilibrium theory, one takes decisions based on market prices. These prices reflect the interactions between all players, but they remain external to the agent, unlike in the mean field theory, in which the effect of the large community is endogenous. This theory is becoming popular in many other domains, like traffic congestion, consumer behavior, or information technology.

Our efforts in this domain are supported by NSF grants and RGC-GRF grants. With Jameson Graber we have obtained significant results in Mean Field Games application to economic problems, related to the exploitation of exhaustible resources. As mentioned above, cybersecurity offers interesting possibilities of using mean field concepts.

Another quite interesting direction is the application of Mean field type control to risk management. In stochastic control, one optimizes always an average, therefore risk is not included. The average will never occur. A random cost will occur, and a risk appears when this random cost is far from its average. The natural idea is to introduce a variance in the cost function. The problem is no more classical and requires mean field type control techniques. We have applied the methodology to investment problems.

5.4. RISKS AND UNCERTAINTIES IN ALTERNATIVE ENERGIES

We are continuing our cooperation with EREN Development. It concerns forecasting wind energy. We recall that there are many forecasting situations in this context. In particular, one must differentiate the investment phase from the operational phase. In the investment phase, the situation is to decide whether or not to install a wind farm in a specific region. This is typically a situation where the methodology of real options applies.

At the operational level, the first problem is to obtain an accurate short term forecast. Indeed, wind energy is most commonly coupled with another energy source, and it is important to assess how much is needed. In addition, the potential surplus of wind energy is a problem since a storage facility has to be viable. Thanks to the support of EREN Development, we have developed methods of various kinds to forecast wind energy in the short term. We have tried to connect short term and long term aspects. We have considered diffusions, whose ergodic behavior is a Weibull probability distribution. This is because the Weibull distribution is commonly used to model long term wind speed. We are now entering in the situation of assessing the level of storage which is needed, in concrete investments. For a given level of storage, we can optimize the profit, resulting from a commitment level, which is a daily decision. We can then proceed with a cost-benefit analysis, to define the optimal level of storage.

5.5. RISKS IN TECHNICAL SYSTEMS

As mentioned in the previous report, we do not benefit anymore of financial support in this domain. Nevertheless we continue a scientific cooperation with Dr. Laurent Mertz, currently Professor at NYU Shanghai.

We have started a new direction, concerning stochastic maintenance. In view of the availability of big data, it is promising to model the degradation of infrastructures and structures, and therefore to develop a methodology of maintenance which is adapted to the random state of degradation. This investigation is at a preliminary stage.

6. PRESENT ACTIVITIES